# SUB-NANOSECOND JITTER, REPETITIVE IMPULSE GENERATORS FOR HIGH RELIABILITY APPLICATIONS

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ABSTRACT

Low jitter, high reliability impulse generator development has recently become of ever increasing importance for developing nuclear physics and weapons applications. This paper describes the research and development of very low jitter (<30 ps), multikilovolt generators for high reliability, minimum maintenance trigger applications utilizing a new class of high-pressure tetrode thyratrons now commercially available. The overall system design philosophy will be described followed by a detailed analysis of the subsystem component elements. A multi-variable experimental analysis of this new tetrode thyratron was undertaken, in a low-inductance configuration, as a function of externally available parameters. For specific thyratron trigger conditions, rise times of 18 ns into 6.0-Ω loads were achieved at jitters as low as 24 ps. Using this database, an integrated trigger generator system with solid-state front-end will be described in some detail.

## Introduction

There are a number of emerging applications for very low jitter repetitive impulse generators, particularly in the nuclear particle physics fields. This paper describes the development of an integrated system for these high reliability applications.[1] The impulse generator was to serve as the Master Trigger Generator (MTG) for a large neutrino detector installation at the Meson Physics Facility of the Los Alamos National Laboratory. Specifically, the MTG was designed to drive the high-voltage pulser illustrated in Fig. 1. The neutrino detector is described in detail elsewhere.[1]

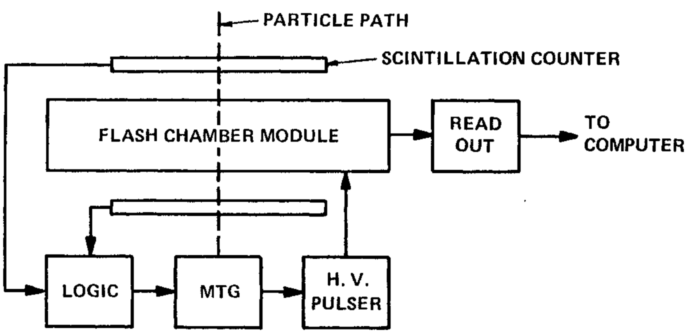


Fig. 1

A block diagram of the MTG is illustrated in Fig. 2. For fastest switching times and minimum jitter, the system was designed around a new high-pressure tetrode thyratron, requiring a detailed analysis of the thyratron before design of the prerequisite trigger and energy storage subsystems could be undertaken.

## Thyratron Characterization

The thyratron switch used to discharge the energy storage system elements into the 3-Ω load is itself a time-varying component as its time-varying inductance and resistance limit the rise time to ≈20 ns, adequate for the present application. In order to minimize switching time, delay time, and jitter, a detailed study of the thyratron commutation characteristics was undertaken for a 3-Ω load resistance and the design

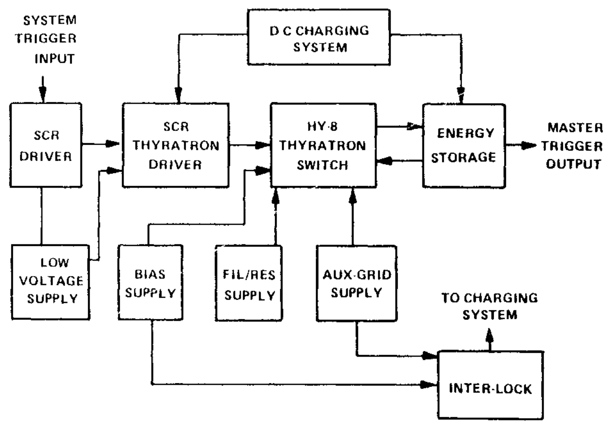


Fig. 2

value energy storage capacity of 0.24 μF, charged to 5 kV using the HY-8 as a switch. As previous work had shown that little performance improvement was achieved for trigger voltages in excess of 2 kV, it was possible then to utilize a very high-speed thyristor driver for minimum commutation time.[2] The basic test circuit was somewhat simplified from the complete trigger generator shown in Fig. 3. Note that the bias and auxiliary supplies are decoupled from the thyratron during commutation by 2-mH rf chokes and that the trigger pulse is applied directly to G2 via C17. This configuration minimizes switching times by eliminating the leading-edge rise time degradation usually seen when a pulse transformer is used.

In the initial study using the HY-8 tetrode thyratron, it was clearly demonstrated that the forward bias on the lower grid greatly reduced the normal grid spike as a result of the low impedance in the pre-ionized grid-cathode area. A representative grid trigger pulse is shown in Fig. 4 with and without the tube in circuit Note the very rapid voltage risetime. The time history of the grid dynamic impedance is illustrated in Fig. 5. During commutation the impedance falls to a minimum of 6 Ω, illustrating the need for a low trigger source impedance when fast switching is desired, as shown in Fig. 6. Throughout the trigger source impedance range of 10 kΩ down to 3 Ω, the jitter and propagation delay

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14. ABSTRACT

**Low jitter, high reliability impulse generator development has recently become of ever increasing importance for developing nuclear physics and weapons applications. This paper describes the research and development of very low jitter (<30 ps), multikilovolt generators for high reliability, minimum maintenance trigger applications utilizing a new class of high-pressure tetrode thyratrons now commercially available. The overall system design philosophy will be described followed by a detailed analysis of the subsystem component elements. A multi-variable experimental analysis of this new tetrode thyratron was undertaken, in a low-inductance configuration, as a function of externally available parameters. For specific thyratron trigger conditions, rise times of 18 ns into 6.0-~ loads were achieved at jitters as low as 24 ps. Using this database, an integrated trigger generator system with solid-state front-end will be described in some detail.**

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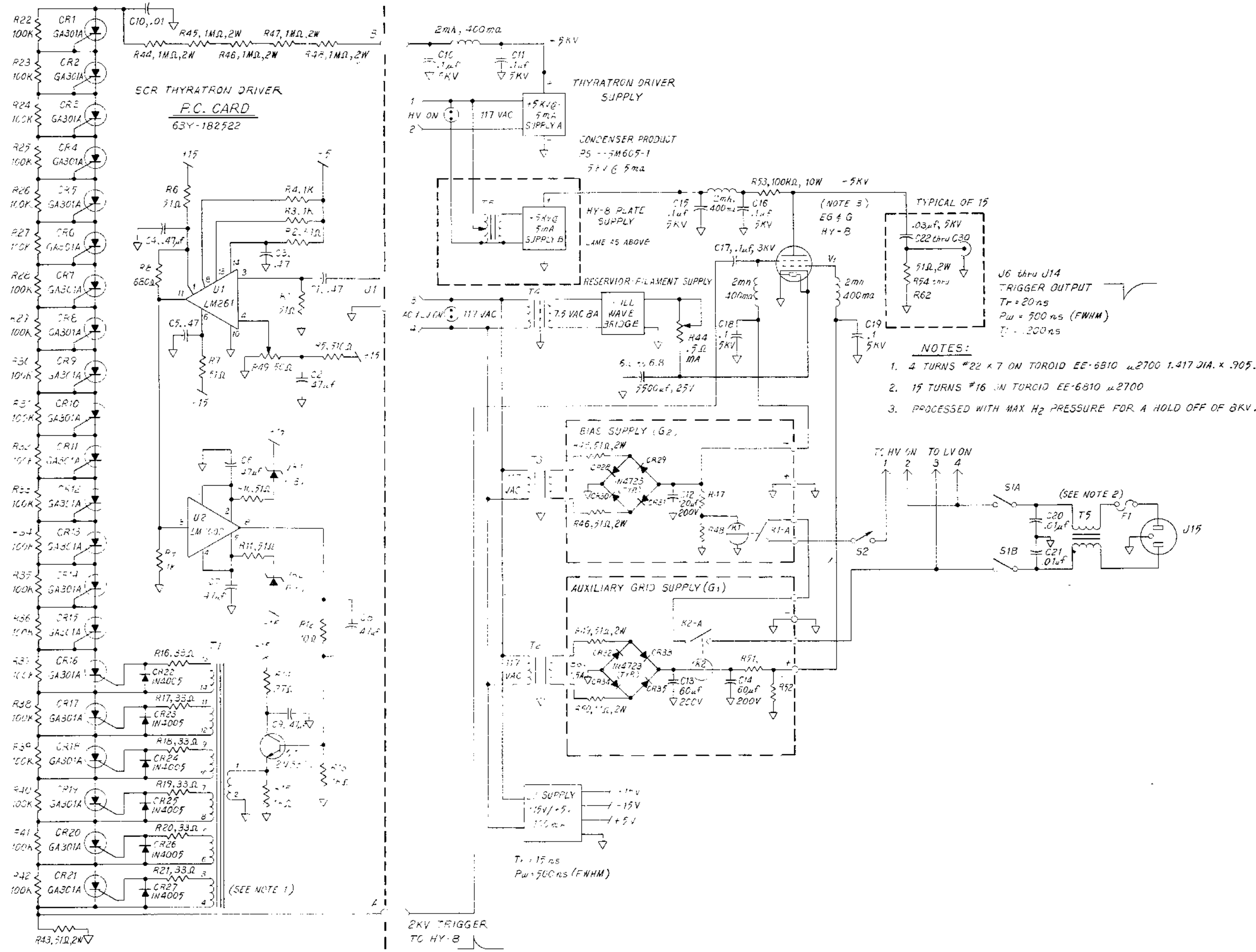
SCR THYRATRON DRIVER
P.C. CARD
63X-182522
THYRATRON DRIVER SUPPLY
CONDENSER PRODUCT
HY-8 PLATE SUPPLY
RESERVIOR-FILAMENT SUPPLY
R53, 100KΩ, 10W
TYPICAL OF 15
J6 thru J14
TRIGGER OUTPUT
Tr = 20 ns
Pw = 500 ns (FWHM)
BIAS SUPPLY (G2)
AUXILIARY GRID SUPPLY (G1)
TO HV ON
TO LV ON
(SEE NOTE 2)
(SEE NOTE 1)
2KV TRIGGER
TO HY-8
Pw = 500 ns (FWHM)
NOTES:
1. 4 TURNS #22 x 7 ON TOROID EE-6810 μ2700 1.417 DIA. x .905.
2. 15 TURNS #16 ON TOROID EE-6810 μ2700
3. PROCESSED WITH MAX H2 PRESSURE FOR A HOLD OFF OF 8KV.

Fig. 3

times changed very little while the current rise time decreased by almost 40%.

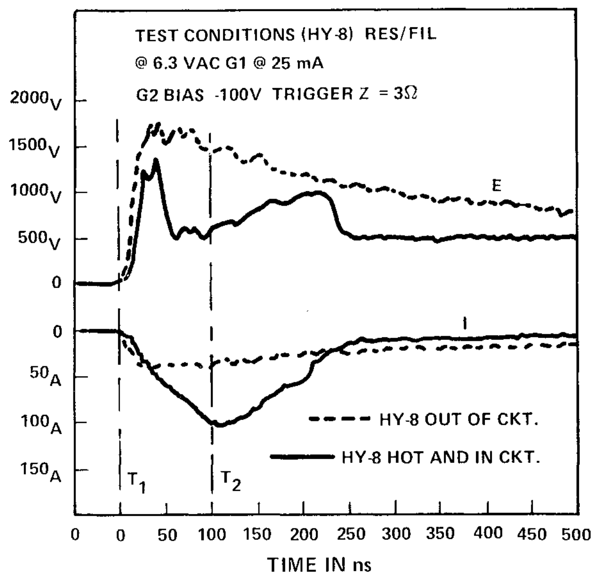


Fig. 4

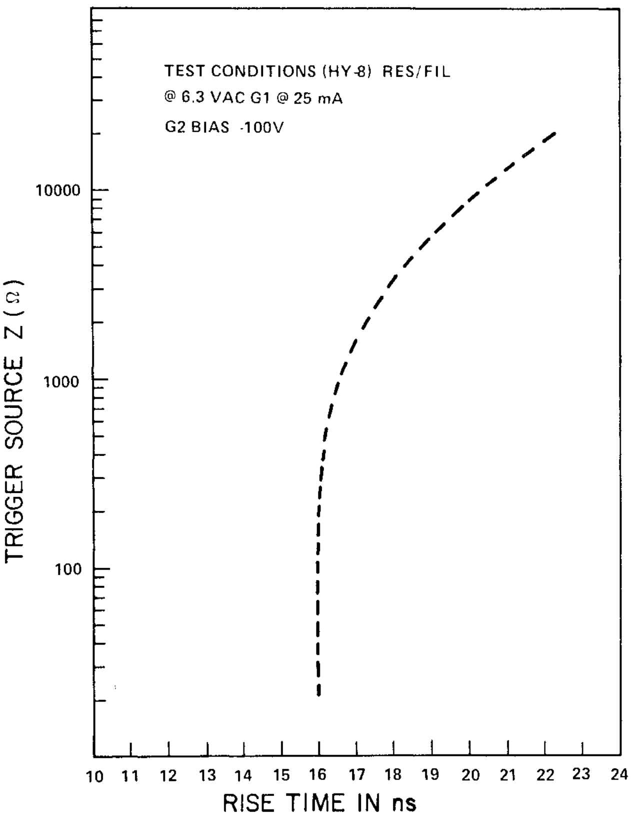


Fig. 6

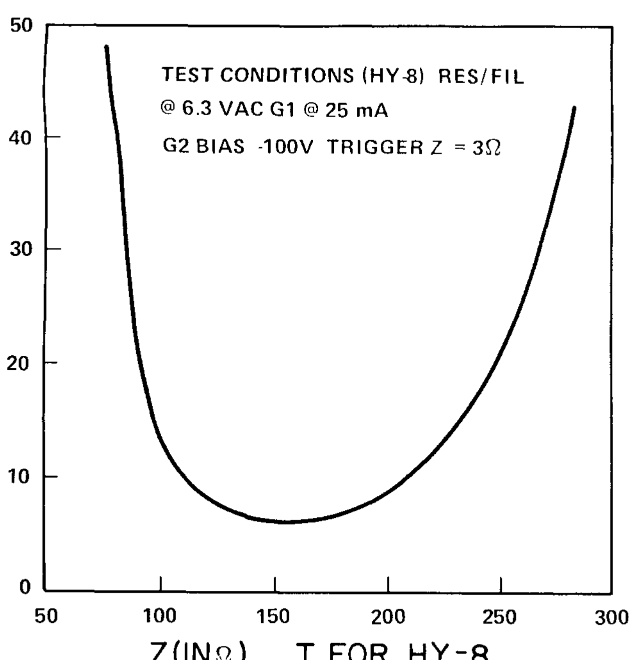


Fig. 5

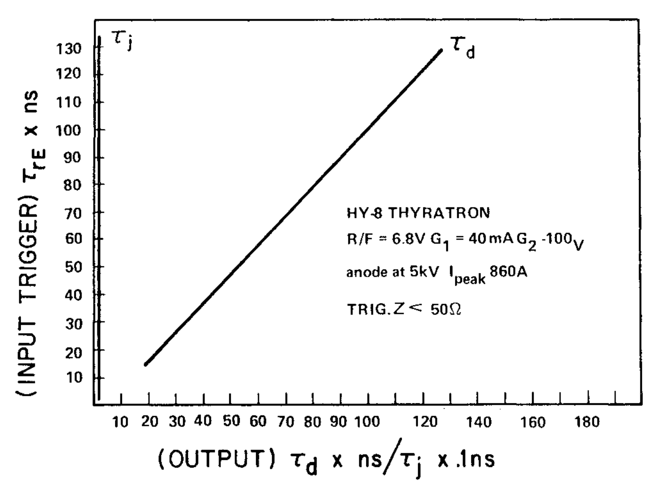


Fig. 7

In varying the trigger pulse rise time from 10 to 100 ns, the dynamics of the thyratron turn-on are significantly affected as illustrated in Fig. 7. The major change was found in decreasing delay time as the rise time decreased. This is a result of the linear increase in the growth rate of the trigger plasma. To meet the delay time specification for the system, the voltage rise time was set to be between 20 and 30 ns. Using the larger of the two, the changes in jitter and delay time with trigger voltage amplitude were evaluated and the results illustrated in Fig. 8. As the trigger voltage increased, the statistical spread in turn-on decreased sharply as the initial electron density and field gradient are elevated resulting in more precisely defined commutation time.

In addition to its input trigger parameters, there are several other areas where thyratron performance optimization can take place. Time jitter may be reduced significantly by powering the reservoir and filaments with regulated dc power instead of ac power. This

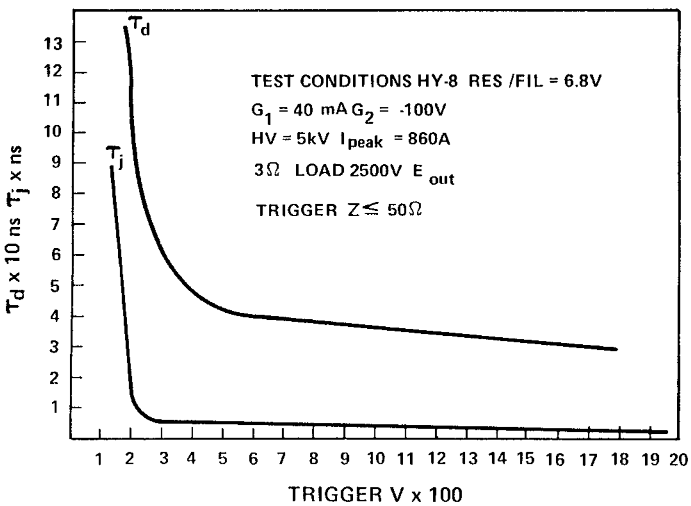


Fig. 8

prevents ac modulation of the initial cathode currents. Furthermore, the power supplied to the reservoir and filaments may be varied to optimize rise time ($T_r$) and delay time ($T_d$). Figure 9 shows the changes in $T_r$ and $T_d$ for various filament and reservoir voltages. These curves show that for minimum $T_r$ and $T_d$, the HY-8 filament and reservoir should be run at their rated maximum (6.8 V). A large reduction in $T_d$ was achieved by supplying the auxiliary grid ($G_1$) of the HY-8 with a positive bias. The auxiliary grid current heavily ionizes the hydrogen in the immediate vicinity of the cathode.

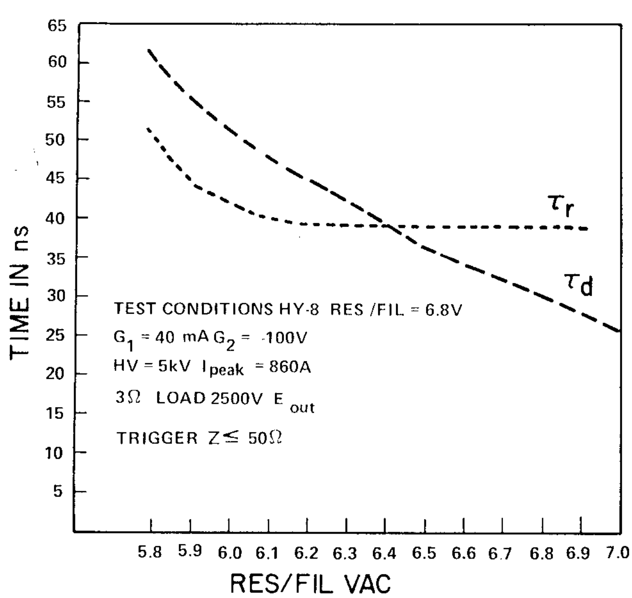


Fig. 9

This means that the initial electron density is well defined and far in excess of statistical background levels (when $I_{G_1} = 0$).[2] Figure 10 shows $T_d$ vs $G_1$ current. The graph shows that above 30 mA of $G_1$ current, there is little improvement in $T_d$; however, at this point, it should be noted that further increases in $G_1$ current can have a deleterious effect on the thyratron's hold-off capability. The same is true for excessive voltage applied to the reservoir. The loss in hold-off capability may be somewhat overcome by supplying $G_2$ with a negative bias. With the exception of the energy storage capacitors and circuit layout geometry, the only other limits are provided by the physical design of the thyratron itself. Based on the above data and design criterion, a high-pressure version of the HY-8 was ordered. Close interactions with the thyratron manufacturer after initial testing produced the present generation of switch tube--the HY-8001. The jitter distribution for the MTG using the HY-8001 is shown in Fig. 11.

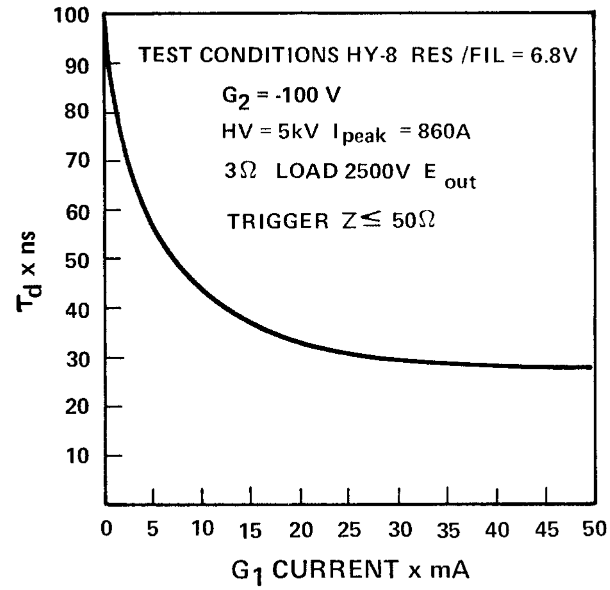


Fig. 10

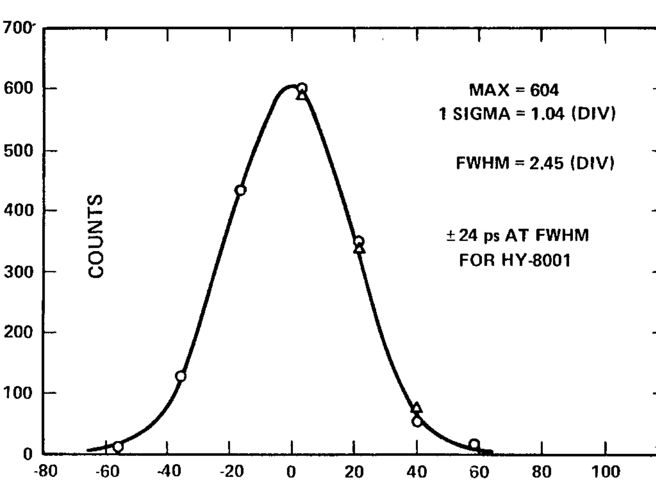


Fig. 11

## Thyristor Thyratron Trigger

The thyratron trigger system was developed to meet or exceed all thyratron trigger requirements previously mentioned. Figure 3 shows a schematic diagram of the thyristor-switch thyratron trigger. The circuit was designed to operate on a ≤10 ns rise time positive input pulse (>0.8 V) into a 50-Ω load, thus making the system compatible with several types of digital logic such as NIM and TTL.

A positive pulse is applied to $J_1$ and triggers the LM261 voltage comparator. The threshold level may be changed by varying the setting of $R_{49}$. The LM261 output is a fast-rising positive pulse which is applied to the input of a LM0002 current driver. The output of the LM0002 is of sufficient power to drive the power transistor $Q_1$ into heavy conduction. This provides a fast current pulse simultaneously to the gate leads of thyristors CR16 through 21. Since the rise time of this gate pulse is fast (<10 ns) in relation to the delay time of the thyristor stack and the peak voltage level is far in excess of minimum trigger level, all six devices commutate virtually simultaneously. The triggering sequence of thyristors 15 through 1 is via a considerably different mode. When the resistance of the first 6 units collapses, a voltage change is impressed on each of the remaining 15, limited in time only by loop inductance and stray capacitance. This voltage change (dV/dt) is 600 V in 0.015 μs corresponding to a dV/dt of 40 kV/μs. This means that each of the remaining 15 units, with a dV/dt rating of 30 V/μs anode to cathode will rapidly commutate. The net result of this circuit configuration is that all 21 thyristors commutate within the delay time of a single device, with current rise time limited only by loop inductance, stray capacitance, and device capability. The impedance of the pulser is controlled by the electrical size of the energy storage capacitors and by the loop inductance. For minimum rise time, loop inductance was reduced to the lowest level possible and at the same time, consistent with all other design criteria. The output appears across the 510-Ω resistor, $R_{43}$. Figure 4 illustrates the output wave form.

## Energy Storage System

The energy storage capacitors and current loop shown in Fig. 12 are conceptually straightforward in geometry. The choice of this design was based on the similarity in output drive requirements of both the thyratron driver and the master trigger generator that is to drive a time-varying load, i.e., a thyratron or a triggered spark gap. The selection of capacitors for energy storage systems which have high output currents, fast rise times, and high reliability is a nontrivial matter. As increasing demands on the current rise times and peak currents are made on energy storage systems, capacitors of specialized construction become a necessity. Capacitors with a low equivalent series inductance and low equivalent series resistance are required.

Shot life, a term denoting the number of discharge cycles becomes a vital parameter with regard to reliability. Operating temperatures and cooling apparatus become an integral part of the electrical design at high power and/or high repetition rates. All of these constraints make capacitor selection a complex process with the above in mind. The capacitors that were selected for the MTG are 0.03 μF at 5 kV with an inductance of ≃10 nH and an ESR of ∿4 Ω. They have an approximate shot life of $1 \times 10^7$ (>99% confidence level). Figure 12 shows their physical placement. Forced air cooling is used to cool both the thyratron and the resistor-capacitor networks.

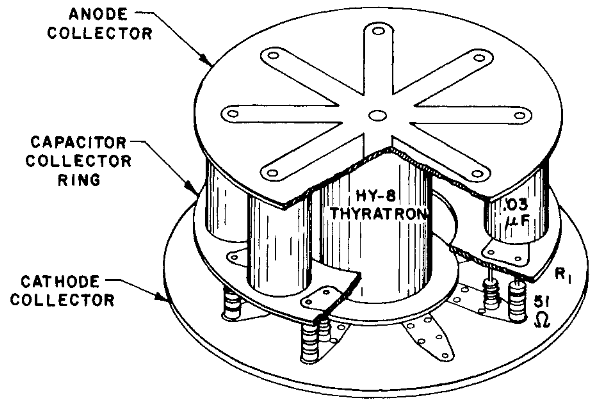


Fig. 12

## Circuit Layout Geometry

In all systems where fast pulses are processed, circuit layout can be and often is as critical as component selection and circuit design. The loop length for the HY-8 (as shown in Fig. 12), was reduced as much as was possible consistent with component size and cooling requirements. The approximate loop length in Fig. 12 is 10 inches giving an approximate loop inductance of 300 nH/loop.

A reduction of 50% in loop length will yield ≈30% reduction in $T_r$ provided that the system is not limited by the switching device itself. The effective system inductance can be reduced in two ways: One method is to provide multiple parallel current paths, in effect paralleling inductances. In a tightly coupled system symmetric and opposite current paths, both of these can lead to significant improvements in pulse rise time. In Fig. 12, the anode collector is a two-sided printed circuit board that also provides the anode-to-capacitor interface. The two current paths on the board are isolated from one another until point of contact. This technique provided a factor of 2 increase in surface conductivity and ∿30% reduction in inductance.

This method was also used in the design of the capacitor collector ring and the cathode collector. In addition, the capacitors and discharge loops are arranged around the HY-8 in the form of a folded spoked wheel. This arrangement along with the parallel current paths and the tight coupling of the circuit elements reduced loop inductance in the HY-8 stage of the MTG to under 30 nH.

Symmetry is an important aspect of the circuit geometry in that each inductive loop (Fig. 12) has an exact opposite such that the magnetic fields, which are set up during the pulse in the loops, tend to cancel one another. There are two benefits from this layout arrangement. One is reduced electromagnetic radiation and the other an effective reduction in loop inductance Figure 3 shows the overall schematic of the MTG. The output of MTG (based on the HY-8001) has a peak current of 6000 A with a rise time of 18 ns. This means that the di/dt is $3 \times 10^{11}$ A/S. The peak output voltage is 5 kV, and system delay is 125 ns with a total system jitter of ≃ ±24 ps.

## Conclusion

Several areas of thyratron performance have been assessed, including trigger source criterion, thyratron operating parameters, and geometrical effects. As a necessary part of the development of an ultra-low jitter trigger system, thyratron trigger source design parameters have been established with regard to output impedance, rise time, jitter, delay time, and voltage level. Thyratron operating parameters, i.e., grid, current, bias levels, filament, and reservoir power for the HY-8, have been accurately determined and a high-pressure version of the HY-8001 has been developed. Component layout has been shown to be of vital importance. The present system (MTG) has demonstrated itself to be both versatile and extremely reliable, with a shot life far in excess of $10^7$ shots and reliability rating of 99.2% over its operating history. At present, a low-inductance version of the HY-8001 is in process and could reduce current rise time by as much as 40%. This will provide a di/dt of $\approx 5 \times 10^{11}$ A/S. There remain areas for further development, particularly in reducing rise time and delay times even further.

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